

Table 1.4: Most common forms of nitrogen (Killpack and Buchholz, 1993).

Form of Nitrogen	Chemical Symbol	Description
Organic Nitrogen	C*-NH ₂	Nitrogen bound to a carbon-containing compound; it exists in many different forms, such as in proteins, DNA, RNA, hormones and enzymes; microorganisms convert it to ammonium then into nitrate
Ammonia	NH ₄	Inorganic, soluble and unstable in water; toxic to fish; plants can uptake ammonia; easily volatilized to the atmosphere
Nitrite	NO ₂	Inorganic form of nitrogen; rarely found in nature as microorganisms quickly convert nitrite to nitrate
Nitrate	NO ₃	Inorganic; highly soluble; the most oxidized form of nitrogen found in nature; plants can easily uptake nitrate; form most identified as groundwater pollutant; cause of eutrophication
Dinitrogen gas	N ₂	Most common form; makes up 78 percent of the atmosphere; cannot be directly used by plants, but is taken into the soil by nitrogen fixation

* C represents a complex carbon compound.

Methemoglobinemia:

Also known as "blue baby syndrome"; a condition where nitrate is converted to nitrite in the body. The nitrite interferes with the blood hemoglobin's ability to carry oxygen, which can cause tissues to become blue in color. This condition may be fatal if untreated.

Organic nitrogen is generally not harmful to humans or the environment. However, organic nitrogen may be converted by microorganisms to nitrate. Nitrate can contribute to the eutrophication of water systems. Excessive nitrate causes algal blooms to form. The blanket of algae spreads across the surface of the water, blocking sunlight from reaching bottom-dwelling plants. These plants die and decompose, depleting the bottom layer of water of oxygen. Eventually the algae will die and decompose, further reducing the oxygen concentration in the water. When the water body is depleted of oxygen it can no longer support aquatic life.

Excessive nitrate levels in drinking water can cause human and animal health problems. **Methemoglobinemia**, also known as "blue baby syndrome," strikes human infants. The baby's blood

cannot transport oxygen adequately, causing the infant's mouth, hands, and feet to turn blue. The infant may experience respiratory distress, vomiting, and death if untreated. The drinking water standard for nitrate-nitrogen is ten milligrams per liter (Code of Federal Regulations, 2004). In fish, there is an analogous "brown blood disease." Pregnant cows drinking nitrate-enriched water may suffer spontaneous abortions, and forage fertilized with high levels of nitrates may be toxic.

Gaseous ammonia is an air pollutant. Exposure to ammonia can trigger asthma and other respiratory problems in humans, livestock, and other mammals. Dissolved ammonia is toxic to fish and other aquatic organisms.

b. Phosphorus

Phosphorus is abundant in nature and like nitrogen, essential for all life. Organisms require phosphorus for energy transport, the production of DNA, RNA, phospholipids, bone, nucleic acids, and the activation of hormones and enzymes (Corbin, 2004).

Phosphorus is the least mobile of all the macronutrients. There are only two primary species of phosphorus—inorganic, sometimes called **orthophosphate**, and organic. Phosphorus principally moves through the environment as a phosphorus-oxygen complex called phosphate (PO_4^{3-}). **Figure 1.2** illustrates the phosphorus cycle. The earth's crust is the primary reservoir of inorganic phosphates. Rocks exposed to the atmosphere expand and contract with changing weather conditions, weakening their structures. Precipitation, especially **acid rain**, further weakens rocks. Small fragments of rock break off in this weathering process and release inorganic phosphates to the soil. Plants take up inorganic phosphates

from the soil, converting them to organic phosphates in their biomass. Animals consume the plants, absorbing the organic phosphates into their bodies and passing the organic phosphorus up the food chain. Manure is rich in both organic and inorganic phosphates. Decomposers consume manure, plant **biomass**, and animal carcasses, converting the organic phosphates into inorganic phosphates. These phosphates are returned to the soil and the cycle begins anew.

Phosphorus is a necessary element for animal and plant life, but when too much is released into the environment it can become a hazard. Soil can hold large amounts of phosphorus, but it is not a bottomless reservoir. Soil phosphorus may leach, runoff, or erode away, contaminating surface water. Phosphorus is the most limiting nutrient for aquatic growth plants; an abundance of dissolved phosphorus in water will allow massive algal blooms to form, paving the way for eutrophication. Phosphorus can also contribute to reduced water clarity.

Orthophosphate:
Inorganic phosphate.

Acid rain: Any form of precipitation with a pH less than 5.6, the normal pH of rain. Nitrogen oxides (NO_x) and sulfur dioxide (SO_2) released into the atmosphere, generally by anthropogenic sources, turn into acids, lowering the pH of precipitation. Acid rain is harmful to vegetation, soils, and waterbodies.

Biomass: The total dry mass of an individual or population.

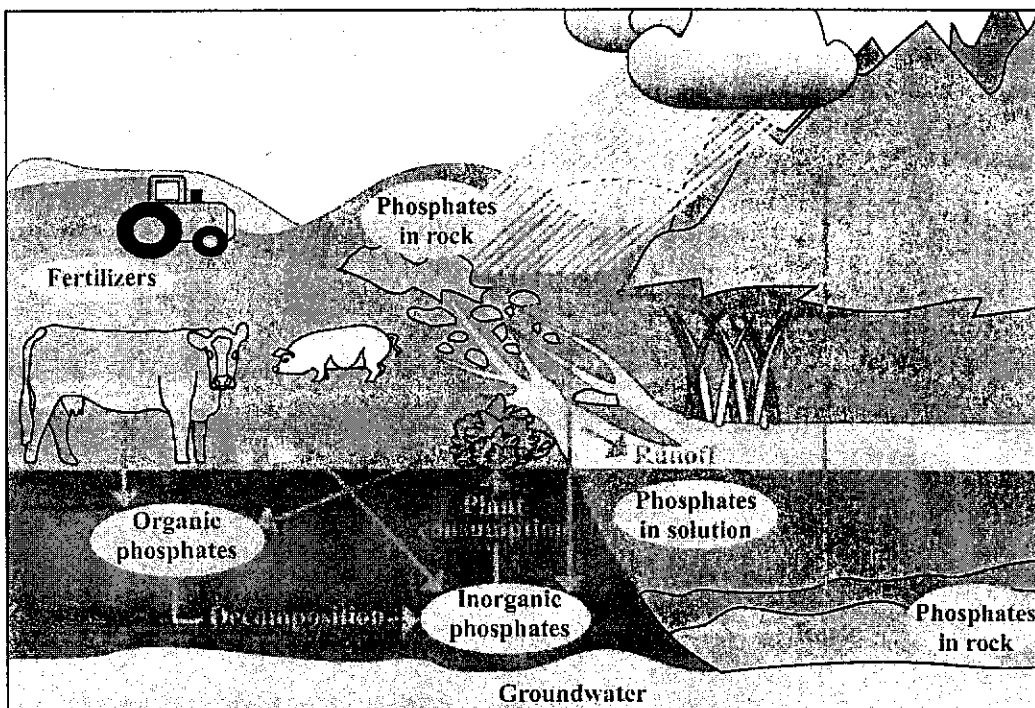


Figure 1.2: Phosphorus cycle (C. White, 2004).

Turbid: Cloudiness caused by particles suspended in liquid.

Aerobic: An oxygenated environment or requiring an oxygenated environment to survive.

Protozoa: A one-celled animal that is larger and more complex than bacteria.

Vector: An agent that transfers a disease or pathogen from one organism to another.

Salmonella: A bacteria found in the digestive tracts of animals that can cause food poisoning in humans.

E. coli: *Escherichia coli*; a type of bacteria found in the digestive tracts of all mammals that may be used as an indicator organism to determine if pathogens are present. E. coli OH:157 is a pathogenic strain of the bacteria.

1.3.2 SUSPENDED SOLIDS

The tiny particles of clays, silts, and organic matter in water are known collectively as suspended solids. Suspended solids may come from decaying plant matter, erosion, industrial waste, sewage, and manure. The presence of suspended solids causes water to be **turbid**.

Turbid water prevents sunlight from reaching aquatic vegetation. This decreases the rate of photosynthesis, reducing the amount of dissolved oxygen in water. If oxygen levels drop too low the result can be a fish kill. Low levels of dissolved oxygen can also impede **aerobic** decomposition. Suspended solids can prevent aquatic creatures from seeing and catching food. The solids may clog fish gills, impair the development of fish eggs, and depress the immune systems of aquatic animals. Suspended solids also provide a binding site for pathogens and other water contaminants, especially metals. Turbidity problems may reduce the habitat quality and ability of the waterbody from being used for recreational or drinking water purposes. Suspended solids are a leading contributor to the number of US waterways considered to be impaired (United States Environmental Protection Agency, 2004).

1.3.3 PATHOGENS

Manure may contain pathogens. When animals defecate, they shed helpful bacteria and disease-causing bacteria, viruses, and **protozoa**. The helpful bacteria aid in digestion; all mammals carry a resident population of bacteria in their gastrointestinal tract. The harmful pathogens can cause diarrhea, gas, or even death in livestock. A single gram of manure may contain billions of fecal bacteria (Sobsey et al., 2004).

Manure pathogens can contaminate surface waters and wells when manure is washed off the land in a runoff event. Pathogens may also reach groundwater and aquifers via percolation. Produce and other foods can become contaminated when pathogen-laden manure is applied as fertilizer. Pathogens can be spread by **vectors** such as insects and birds; however, humans are most often exposed to manure pathogens from polluted drinking water, tainted food, and swimming in contaminated water. Pregnant women, the very young, the very old, and individuals with compromised immune systems are those most at risk from these pathogens. This is true among livestock as well.

Table 1.5 lists a few common pathogens and the illnesses they cause. *Escherichia coli* OH:157 is a pathogenic strain of bacteria. *Salmonella* is also a bacterium, while *Cryptosporidium parvum* and *Giardia lamblia* are protozoa.

Table 1.5: Common pathogens transmitted to humans from animal manure (United States Environmental Protection Agency, 2004).

Pathogen	Disease	Symptoms
<i>Escherichia coli</i> OH:157 (E. coli)	Colibacillosis, coliform mastitis-metritis	Diarrhea, abdominal gas
<i>Salmonella</i> spp.	Salmonellosis	Abdominal pain, diarrhea, nausea, chills, fever, headache
<i>Cryptosporidium parvum</i>	Cryptosporidiosis	Diarrhea, weakness, abdominal cramping
<i>Giardia lamblia</i>	Giardiasis	Diarrhea, abdominal pain, abdominal gas, nausea, vomiting, headache, fever

The detection methods used to determine the presence of pathogens are always evolving. Traditionally, indicator organisms such as **fecal coliform** are used. Fecal coliform are not pathogenic, but co-exist with pathogens in the gastrointestinal tracts of mammals and indicate the presence of manure. Enterococci, another family of bacteria that exist in the digestive tracts of mammals, is becoming more prevalent as an indicator organism.

1.3.4 BIODEGRADABLE ORGANICS

The biodegradable organic compounds in manure are proteins, carbohydrates, oils, and fats. These compounds are in undigested feed, byproducts of digestion, hair, and bedding. **Table 1.6** lists these compounds and the typical levels they are found in manure.

These biodegradable organic compounds are oxygen-demanding substances. They are consumed by aerobic bacteria and other microorganisms for energy, growth, and reproduction. The digestion process is oxygen-intensive. As the microorganisms begin a feeding frenzy they use up the dissolved oxygen in the water, reducing the amount of oxygen available for fish and other aquatic creatures. The oxygen levels can be depressed to the point of causing massive fish kills.

The amount of biodegradable organic compounds present in water may be measured in terms of a five-day **biochemical oxygen demand test** (BOD_5) or **chemical oxygen demand test** (COD).

1.3.5 MANURE GASES

Manure releases volatile gases to the surrounding environment. These manure gases can cause a range of problems—from odors, to serious health and environmental impacts, to explosive situations. The kind and amount of gas produced depends on the animal. One study identified 32 different volatile compounds from cattle manure, 17 from poultry manure, and more than 50 from swine manure (Iowa State University, 2004).

Odor-causing compounds originate from a variety of sources. Some are a direct result of metabolic processes in the gastrointestinal tracts of livestock while others are generated when the manure decomposes or during treatment. Anaerobic digestion, whether controlled as a treatment process or uncontrolled in the natural degradation of manure, is the largest contributor of odorous compounds. During anaerobic digestion, acid-forming bacteria convert organic matter to volatile fatty acids (VFAs).

Fecal coliform: A group of bacteria in the family Enterobacteriaceae and commonly found in the digestive tracts of all mammals. The presence of fecal coliform in water may indicate fecal contamination and the existence of pathogens.

Biochemical oxygen demand (BOD): A measure of the amount of oxygen needed by aerobic microorganisms to break down solids and organic matter present in wastewater. Although BOD is not a specific compound, it is defined as a conventional pollutant under the federal Clean Water Act. The BOD_5 test is a five-day laboratory test to determine the amount of oxygen available for biochemical oxidation in a sample.

Chemical oxygen demand (COD): A measure of the oxygen-consuming capacity of inorganic and organic matter present in wastewater. COD may be higher than BOD because the chemical oxidant may react with substances that bacteria do not consume.

Table 1.6: Composition of biodegradable organic compounds in manure (Metcalf and Eddy, 2003).

Biodegradable organic compound	Range found in manure (percent)
Proteins	40 - 60
Carbohydrates	25 - 50
Fats and oils	8 - 12

Methane: A gas (CH_4) produced when anaerobic bacteria decompose organic matter. Methane is a strong greenhouse gas. Methane can be used as fuel.

Hydrogen sulfide: A colorless, flammable, toxic gas (H_2S) that smells like rotten eggs, produced during the decomposition of organic matter.

Mercaptans: A group of volatile compounds formed from carbon, hydrogen and sulfur. Mercaptans produce a very offensive odor.

Greenhouse gas: A gas that captures heat emitted from the earth, contributing to global climate change.

These VFAs are smelly, but under appropriate treatment conditions they will degrade to **methane** and carbon dioxide, which are odorless. Ammonia and amines are produced when urine and fecal matter react with each other, both producing sharp odors. Phenolics and N-heterocycles are produced by microbial activity. Sulfur-reducing microorganisms, also present during anaerobic digestion, convert sulfide to **hydrogen sulfide**, diethyl sulfide, and **mercaptans**. These compounds often smell like rotten eggs. It is important to note that odors can permeate from barns, loafing lots, pastures, and pre-treatment storage facilities. Odors from these locations will not be affected by manure treatment technologies.

Ammonia, carbon dioxide, hydrogen sulfide, and methane are the four manure gases of principal concern. These gases are harmful to the environment and impact human and animal health. Carbon dioxide and methane are **greenhouse gases** that contribute to global warming. Other gases are components of acid rain.

Exposure to these gases can cause both short-term and long-term health affects. Mild irritation or headaches may occur at low levels of exposure

while asphyxiation or death can occur with acute exposure. Enclosed areas that may contain manure gases should be avoided. These areas should only be entered if a self-contained breathing apparatus is worn. If someone falls ill due to exposure to manure gas do not attempt to rescue them—call trained professionals for emergency assistance. **Table 1.7** summarizes the environmental and health effects of these gases.

1.4 MANURE COLLECTION AND HANDLING

Before manure can be treated and utilized it must be collected from the animal housing. Manure can be collected as a liquid, as a solid, or as a semi-solid. The initial cost of the system must be weighed against the labor requirements, maintenance needs, replacement part cost, downtime, environmental benefits, animal health benefits, worker health benefits, and financial benefits. The type of bedding used will also dictate the collection system choice.

Table 1.7: Select manure gases and exposure information (Ohio State University, 2004).

Manure Gas	Odor	Exposure Limit (ppm)	Health Impacts	Environmental Impacts
Ammonia (NH_3)	Pungent	10	Irritation to eyes and nose; asphyxiation at high levels	Contributes to acid rain when oxidized
Carbon dioxide (CO_2)	None	5,000	Drowsiness; headache; asphyxiation at high levels	Greenhouse gas
Hydrogen sulfide (H_2S)	Rotten Eggs	10	Headache; dizziness; nausea; loss of consciousness; death	Highly flammable; when oxidized to sulfur contributes to acid rain
Methane (CH_4)	None	1,000	Headache; asphyxiation	Greenhouse gas; explosive at five to 15 percent mixture with air

1.4.1 BEDDING

Bedding keeps animals comfortable and healthy by absorbing urine and fecal matter. The choice of the bedding should be compatible with the manure collection system, the treatment technology used to treat the manure, and the management of the farm. Loose sand, hay, sawdust, wood chips, cotton gin waste, and shredded newspaper are all common bedding choices. Rubber-filled mattresses with a layer of organic material on top have been used in the dairy industry. Treated manure solids may be recycled and used as bedding.

1.4.2 LIQUID HANDLING

Flushing is a common method of manure collection with swine and dairy operations. A large volume of water is used to push the manure into a collection area. Flush water may be totally clean water or recycled **supernatant** from solids separation or treatment processes. A reliable supply of clean water can be costly, but some clean water is usually added to recycled water. About ten to 20 percent of the manure volume handled each year is supplemental clean water used to decrease the solids content of recycled flush water (DeBruyn and Hilborn, 2001).

The flush water is typically held in a large tank above ground to increase the potential energy required to push the manure out of the barn. Harvestore® or Slurrystore® silos may be used to store the flush water. **Figure 1.3** is a photograph of manure being flushed into an earthen storage pond.

The storage facility for the flushed manure should be sized to

appropriately contain the flush water and manure, while still maintaining adequate **freeboard**. The collection of milking center wastewater, direct precipitation, and runoff will increase the storage facility size, increasing the total cost of the system. It is of utmost importance that storage facilities are designed and maintained properly; earthen storage facilities should be lined with either a compact clay or plastic liner to prevent contaminants from migrating to groundwater and drinking water wells.

Liquid handling increases management efficiency and savings in labor. Manure diluted with flush water can be used for **fertigation**. Liquefied manure may be better suited for certain treatment processes. However, liquid manure handling is more energy intensive and the design and

Supernatant: The liquid standing above the layer of solids after settling or treatment.

Freeboard: The vertical space between the surface of a water body and the top of the surrounding embankment.

Fertigation: The irrigation of nutrient-rich water for fertilizer using irrigation equipment.



Figure 1.3: Flushed manure entering storage facility (K. Christophel, 2002).

Macropore: Large opening in unsaturated soils formed by the shrinking and cracking of soils, plant roots, soil fauna, or by tillage operations. The presence of macropores may encourage preferential flow of water and contaminants to groundwater.

Hopper: A funnel-shaped receptacle that moves the manure via gravity to storage or treatment units.

Soil amendment: Compounds used to build and maintain the physical properties of soil.

equipment are more expensive than semi-solid handling. Additional land is required for the storage of the liquefied waste, as well as land for assimilation. Liquefied manure is also susceptible to movement through **macropores**. The high-risk associated with containing massive volumes of nutrient-rich fluid in one location is unacceptable for many people, based on the growing history of catastrophic effects of manure overflows.

1.4.3 SOLID AND SEMI-SOLID HANDLING

Solid and semi-solid manure handling systems allow for the use of storage pits beneath slatted barn flooring. The manure drops through the slats to a pit beneath the barn floor where it is stored and periodically removed. This method of collection is generally labor-free, except for the periodic clean-outs of the storage area. However, dangerous manure gases may collect in the pit and the slatted floors may break, injuring animals and workers.

Scraping is another method used to collect solid or semi-solid manure. A tractor-mounted blade or skid steer is used to scrape the manure from the alley into a **hopper** or collection area. Scraping requires equipment and employees to run it. This method of manure collection is used most often with dairies. The alleys are scraped two or three times a day, while the cows are being milked—when they are out of the way. The animals tend to be dirtier with this method.

Solid and semi-solid handling systems have a higher level of societal acceptance over liquid handling systems. These systems pose fewer

environmental risks—solid manure does not flow if the storage or transport system fails. Solid manure is not an immediate threat to areas riddled with macropores. However, macropore movement can be an issue with semi-solids. Solid and semi-solid systems generally do not require specialized equipment, but are more labor intensive than liquid handling systems. Additional bedding is required for animal comfort when using solid and semi-solid collection systems.

1.5 MANURE MANAGEMENT

Livestock operations continually produce manure, and managing manure is not a simple task. Knowledge from several different subjects is utilized in order to effectively manage manure. These areas include nutritional sciences, agronomy, microbiology, chemistry, engineering, economics, and social sciences.

1.5.1 DISCIPLINES

Many farms have a nutritionist—the person who determines the feed rations for the animals in order to optimize animal growth and production. Depending on the kind of animal, a nutritionist may be able to recommend a change in feed rations or the addition of certain enzymes that will help to control the levels of nutrients that are present in manure.

Agronomy is the discipline dealing with how plants grow. Agronomy is related to manure management because manure can be used as a **soil amendment** or fertilizer. However, farmers cannot just dump manure on a plant and expect it to grow. Plants can

only take up nutrients at certain stages in their life cycle and they can only take up nutrients in particular forms. Manure too high in nutrients can kill a plant. Manure applied when the plant does not need it or when soil conditions are not right can lead to pollution.

Microorganisms are the powerhouses of manure management. Bacteria and fungi are responsible for most of the nutrient conversions, odor reductions, and manure stabilization that occurs during treatment. Elemental knowledge of microbiology ensures that the different populations of microorganisms are operating effectively.

While microorganisms are the force behind many manure treatment technologies, their results are expressed in chemical terms. Manure and soil tests, important to manure management, are also expressed in chemical terms. Familiarity with such terms and the ability to interpret these results are important.

Some manure storage and treatment facilities are engineered structures. In fact, many of these facilities require the design to be signed by a professional engineer in order to receive a permit.

The economics of manure management must be considered. Manure storage and treatment technologies cost money to design, install, operate, and maintain. Normally, a capital investment on a farm is expected to pay for itself over time. However, investments in manure management usually do not produce a positive return. This is not saying that there is no value in the soil-building and fertilizing qualities of manure. Rather, that manure management may not directly lead to significantly

higher profitability—consumers do not make the connection between the price of food they purchase and the value of a cleaner environment that is provided by sound manure management.

Last but not least, manure management requires a bit of social science. Positive farm-neighbor relations must be established and maintained. While proper manure management will give little cause for complaint, a savvy farm operator can continually improve relations by providing free produce, fertilizer, snow removal, annual picnics, open houses, and other services.

1.5.2 NUTRIENT MANAGEMENT PLANS

To coordinate all these disciplines a comprehensive nutrient management plan (CNMP) is created. Many different agencies and individuals are involved in manure management and CNMPs at the local, state, and federal levels. The Soil and Water Conservation District (SWCD) and Natural Resource Conservation Society (NRCS), a branch of the United States Department of Agriculture (USDA), also oversee manure management issues.

To create a nutrient management plan, advisors from the SWCD as well as the NRCS may be called upon. The nutrient management planner may be an employee of the SWCD, the NRCS, or may be a private consultant. Many states require the nutrient management planner to be certified in that particular state.

A comprehensive nutrient management plan is a very detailed document that inventories the resources and problems on the farm, as well as a schedule of actions that the farm will take regarding erosion control and manure management. A CNMP should manage the amount, source, placement, form, and timing of nutrient and soil amendment application timing. Investigations may include soil testing; manure nutrient analysis; the manure spreading schedule and method of incorporation; and nutrient credits from cover crops, green manure, and legumes. The CNMP should dictate how the physical, chemical, and biological condition of the soil should be maintained or improved. Ultimately, the CNMP should form a plan to minimize agricultural non-point source pollution.

A system combining biological, physical, or chemical approaches is always better than relying on a single approach. A system of approaches attacks the pollutants using different tools to treat the manure more thoroughly. A system of treatment processes also provides multiple barriers between the source of pollution and the environment—if one technology fails or needs repair the manure can still be partially treated by the remaining components.

There are several factors to consider when selecting a treatment technology or system of treatment technologies. **Table 1.8** lists some of these factors.

It is imperative to remember that treatment does not eliminate manure; there will always be a solid or liquid end-product requiring further treatment, utilization, or disposal.

1.7 LAND APPLICATION OF MANURE

Farmers have applied manure to land for thousands of years. Ancient farming communities saw the valuable benefits of manure as fertilizer. When applied correctly, land application of manure is a cost-effective and sustainable practice that can build soil **tilth**, increase the water holding capacity of the soil, and provide essential nutrients for plant growth. Land applying manure at agronomic rates promotes microbial growth, increases organic matter content, and can even decrease the potential for runoff and erosion. Runoff reductions of two to 62 percent and soil erosion reductions of 15 to 65 percent have been observed as effects of manure application (Gilley and Risse, 2000). Even when the manure was not applied

A nutrient management plan should be easy to understand and follow. It is what guides farms in their decisions of what to do with manure. While federal and state legislation is moving towards requiring most livestock farms to have CNMPs, it is a tool that all farms, regardless of size, can benefit from.

1.6 TREATMENT APPROACHES

There are three approaches to treating manure. Manure may be treated biologically; microorganisms, plants, or other live organisms remove potential pollutants or change them into less harmful compounds. Manure may be treated physically; physical processes such as screening, filtering, or settling are used to remove potential pollutants. Manure may be treated chemically; chemical reactions are used to remove pollutants or change them into less harmful compounds.

Tilth: The physical condition of a soil in relation to its ability to sustain plant growth.

Table 1.8: Factors to consider when evaluating and selecting a treatment approach (adapted from Metcalf and Eddy, 2003).

Factor	Comment
Approach applicability	Evaluated on basis of past performance, reliability, complexity, data from full-scale plants, published research, pilot-scale plants
Manure production rate and variability	Some treatment processes are not compatible with all rates
Manure characteristics	Affects the types of processes that are most effective and the requirements for appropriate operation
Inhibiting and unaffected constituents	Some constituents may be inhibitory to processes; some constituents may be unaffected by treatment
Climatic constraints	Temperature affects the rate of reaction of most chemical and biological processes and may affect physical processes as well; warm temperatures may accelerate odor generation and inhibit atmospheric dispersion
Treatment residuals	Types and amounts of solid, liquid, and gaseous residuals produced during treatment; how these residuals will be further treated or disposed of
Environmental constraints	Geological, hydrological, prevailing winds, and proximity to residential areas may restrict or affect the use of certain processes; process noise and traffic may also affect site selection
Energy requirements	Energy requirements and projected future energy costs should be considered for cost-effective designs
Personnel requirements	Number and skill level of workers; training
Operation and maintenance	Special operating and maintenance requirements should be considered, as well as spare parts availability and cost
Compatibility and adaptability	Some unit processes may be better suited to existing processes than others; prepare for future changes
Economic life-cycle analysis	Consider initial and long term operating and maintenance costs—the system with the lowest initial costs may have the highest operation and maintenance costs; sources of available funding may also affect process selection
Land availability	Sufficient space to accommodate current facilities; room for future expansion; buffer areas to minimize visual, noise, odor impacts

annually, runoff and erosion reductions continued; there seems to be a residual benefit from previous manure applications. Land application is a positive means to utilize the liquid and solid residuals from manure treatment.

Inappropriate manure applications or applying manure at disposal rates rather than agronomic rates creates an ecological and economic liability. Industrial livestock facilities use big-gun style irrigation equipment to drench soils with untreated liquefied manure. These facilities apply manure at disposal rates that create manure ponding on the soil, runoff, water and air quality problems. Crops grown in the nutrient-laden fields are not fit for human or animal consumption; extremely high levels of nitrogen can make these plants toxic. Neighbors are forced indoors by the overwhelming odors released into the air during pumpdown of the storage facilities and by the drifting plumes of liquefied manure projected into the air.

A conscientious farmer can apply manure and reap the benefits while avoiding potential pollution problems. Farmers should not apply manure in areas located in environmentally sensitive watersheds. Manure should not be applied to soils with high nutrient levels, to saturated or frozen soils, or soils located in flood plains. Manure should not be applied just prior to, during, or just after a rainfall event. Manure should always be applied at agronomic rates, a rate consistent with the current soil nutrient levels and the plant needs. Odors from land application of manure can be avoided by careful timing. Most odors occur when the manure is removed from the storage facilities, but windbreaks may be used to prevent

odors from spreading across the landscape. Prevailing winds should be considered during storage pumpdown and land application. Manure should not be applied during holidays, weekends, or other times neighbors are likely to be outside.

Manure can be land applied by a variety of methods. Manure may be broadcast, or spread, as a solid or semi-solid on the soil surface. Liquid manure may be sprayed onto the soil using irrigation equipment. These methods of manure application can increase odor, drift, and runoff problems. Incorporation (mixing the manure with the soil) minimizes the amount of manure on the soil surface, decreasing odor and pollution potential. Odor reductions of 20 to 90 percent may be achieved, depending in the incorporation method (Hanna et al., 2000). A balance between the manure incorporation method and conservation tilling must be struck—incorporation disturbs the soil surface and reduces plant residue cover, which can lead to erosion. Discs, rakes, chisels, and knives are implements used to create an opening in the soil surface to deposit the manure into. Implements may be paired together in order to pull soil or plant residue over the manure-filled opening. Specialized injection equipment may be used to actually inject manure into the soil. Injection further reduces the potential for odor and runoff problems and is a method of incorporation that minimizes soil disturbance.

REFERENCED MATERIALS

- Agricultural Research Service. 2003. Food Safety Research: A Focus on Animal Manure Management. United States Department of Agriculture. www.nal.usda.gov/fsrio/research/fsheets/fsheet03.htm. Last visited 28 July 2004.
- Bickert, W.G. 2001. Manure system selection consideration and goals. Dairy Manure Systems: Equipment and Technology. Proceedings from Dairy Manure Systems: Equipment and Technology. Natural Resource, Agriculture, and Engineering Service NRAES-143. March 20-22, 2001. Rochester, New York.
- Bicudo, J.R. 2001. Ponds and lagoon for liquid effluent treatment. Dairy Manure Systems: Equipment and Technology. Proceedings from Dairy Manure Systems: Equipment and Technology. Natural Resource, Agriculture, and Engineering Service NRAES-143. March 20-22, 2001. Rochester, New York.
- Bonhotal, J. 2001. Managing manure solids. Dairy Manure Systems: Equipment and Technology. Natural Resource, Agriculture, and Engineering Service NRAES-143. Cornell University, Ithaca, New York.
- Bossard, S.E. 2001. Getting manure out of the barn. Dairy Manure Systems: Equipment and Technology. Proceedings from Dairy Manure Systems: Equipment and Technology. Natural Resource, Agriculture, and Engineering Service NRAES-143. March 20-22, 2001. Rochester, New York.
- Burke, D.A. 2001. Dairy Waste Anaerobic Digestion Handbook: Options for Recovering Beneficial Products from Dairy Manure. Environmental Energy Company. www.makingenergy.com/Dairy%20Waste%20Handbook.pdf. Last visited 20 November 2003.
- Chen, Y. and S. Tessier. 2001. Criterion for design and selection of injection tools to minimize liquid manure on the soil surface. Transactions of the American Society of Agricultural Engineers. Vol. 44(6). P. 1421-1428. American Society of Agricultural Engineers. St. Joseph, Michigan.
- Christophel, K. 2002. Photograph of flushed manure entering storage facility. Department of Biological Systems Engineering. Virginia Polytechnic Institute and State University. Blacksburg, Virginia.
- Code of Federal Regulations. 2004. 40 CFR 141.62(b).
- Corbin, K. 2004. Biogeochemical Cycles: The Phosphorous Cycle. Virginia Polytechnic Institute and State University. Blacksburg, Virginia. http://soils1.cses.vt.edu/ch/bio_4684/Cycles/Pcycle.htm. Last visited 27 July 2004.
- Czymmek, K.J., Q.M. Ketterings, L.D. Geohring, G.L. Albrecht. 2003. The New York Phosphorus Runoff Index: User's Manual and Documentation. Prepared for New York State Department of Environmental Conservation and New York State Department of Agriculture and Markets. Cornell University. Ithaca, New York.
- DeBruyn, J. and D. Hilborn. 2001. Storages and the manure management plan. Dairy Manure Systems: Equipment and Technology. Proceedings from Dairy Manure Systems: Equipment and Technology. Natural Resource, Agriculture, and Engineering Service NRAES-143. March 20-22, 2001. Rochester, New York.
- Economic Research Service. 2004. A Safe Food Supply: Glossary. United States Department of Agriculture. www.ers.usda.gov/Emphases/SafeFood/glossary.htm. Last visited 29 July 2004.

- Gilley, J.E. and L.M. Risse. 2000. Runoff and soil loss as affected by the application of manure. Transactions of the American Society of Agricultural Engineers. Vol. 43(6). P. 1583-1588. American Society of Agricultural Engineers. St. Joseph, Michigan.
- Hanna, H.M., D.S. Bundy, J.C. Lorimor, S.K. Mikelson, S.W. Melvin, D.C. Erbach. 2000. Manure incorporation equipment effects on odor, residue cover, and crop yield. Applied Engineering in Agriculture. Vol. 16(6). P. 621-627. American Society of Agricultural Engineers. St. Joseph, Michigan.
- Hoban, T.J., W.B. Clifford, M. Futreal, M. McMillan. 1997. North Carolina producer's adoption of waste management practices. Journal of Soil and Water Conservation. Vol. 52(5). P. 332-339.
- Iowa State University. 2004. Most Frequently Asked Questions About Manure and Manure Management in Iowa. Ames, Iowa. <http://extension.agron.iastate.edu/immag/faqdetails.html>. Last visited 16 July 2004.
- Janzen, R.A., W.B. McGill, J.J. Leonard, S.R. Jeffrey. 1999. Manure as a resource—ecological and economic considerations in balance. Transactions of the American Society of Agricultural Engineers. Vol. 42(5). P. 261-273. American Society of Agricultural Engineers. St. Joseph, Michigan.
- Jesiek, J.B. 2003. Phosphorus management: an analysis of the Virginia P-index. M.S. Thesis. Virginia Polytechnic Institute and State University. Blacksburg, Virginia.
- Kalkhoff, S.J. 2000. Summary of the major water-quality findings from the eastern Iowa basins study unit of the national water quality assessment program. IGWA Quarterly. Vol. 11(3). US Geological Survey. Iowa City, Iowa.
- Ketterings, Q.M., K.J. Czymmek, S.D. Klausner. 2003. Phosphorus Guidelines for Field Crops in New York. Department of Crop and Soil Sciences Extension Series E03-15. Cornell University. Ithaca, New York.
- Killpack, S. and Buchholz, D. 1993. Nitrogen in the Environment: Nitrogen's Most Common Forms. Water Quality Initiative, publication WQ253. University of Missouri University Extension. Columbia, Missouri. <http://muextension.missouri.edu/explore/envqual/wq0253.htm>. Last visited 28 July 2004.
- Livestock and Poultry Environmental Stewardship Curriculum. Lesson 1; Principals of Environmental Stewardship. www.lpes.org/Lessons/Lesson01/01_sec5.pdf. Last visited 28 July 2004.
- Los Alamos National Laboratories. 2003. Elements: Nitrogen. Los Alamos, New Mexico. <http://pearl1.lanl.gov/periodic/elements/7.html>. Last visited 27 July 2004.
- Manel, K.M. and J.D. Slates. 2003. Farmer estimates of manure application rates. Proceedings from 9th International Animal, Agricultural and Food Processing Wastes. Raleigh, North Carolina.
- Metcalf and Eddy, Inc. 2003. Wastewater Engineering Treatment and Reuse. Fourth Edition. McGraw-Hill. New York, New York.
- Murphy, S. 2002. General Information on Solids. City of Boulder USGS Water Quality Monitoring. Boulder, Colorado. <http://bcn.boulder.co.us/basin/data/NUTRIENTS/info/TSS.html>. Last visited 27 July 2004.
- Murphy, S. 2004. General Information on Fecal Coliform. City of Boulder and United States Geological Survey Water Quality Monitoring. Boulder, Colorado. <http://bcn.boulder.co.us/basin/data/NUTRIENTS/info/FColi.html>. Last visited 29 July 2004.

- Ohio State University. 1992. Ohio Livestock Manure and Wastewater Management Guide. Bulletin 604. Columbus, Ohio. http://ohioline.osu.edu/b604/b604_12.htm. Last visited 15 July 2004.
- Ohio State University. 2002. OSU Studies Manure Pathogens, Links to Illness. Ohio State Extension and Purdue Extension Partnership. www2.agriculture.purdue.edu/agcomm/aganswers/story.asp?storyID=2902. Last visited 29 July 2004.
- Ophardt, C. 2003. Phosphorus Cycle Virtual Chembook. Elmhurst College. Elmhurst, Illinois. www.elmhurst.edu/~chm/vchembook/308phosphorus.html. Last visited 27 July 2004.
- Pidwirny, M. 2004. Introduction to the Biosphere: The Nitrogen Cycle. Physical Geography.net: Fundamentals of Physical Geography. Okanagan University College. British Columbia, Canada. www.physicalgeography.net/fundamentals/9s.html. Last visited 27 July 2004.
- Rozdilsky, J.L. 1997. Farm-based Anaerobic Digestion in Michigan: History, Current Status, and Future Outlook. A Report of the Michigan Biomass Energy Program. www.michiganbioenergy.org/areas/anaerobic.pdf. Last visited 20 November 2003.
- Schmidt, D.R., L.D. Jacobson, M.A. Schnitt. 1996. A manure management survey of Minnesota swine producers: summary of responses. *Applied Engineering in Agriculture*. Vol. 12(5). P. 591-594. American Society of Agricultural Engineers. St. Joseph, Michigan.
- Simpkins, W.W., M.R. Burkart, M.F. Helmke, T.N. Twedt, D.E. James, R.J. Jaquis, K.J. Cole. 1999. Hydrogeologic Settings of Selected Earthen Waste Storage Structures Associated with Confined Animal Feeding Operations in Iowa: A Report to the Legislature of the State of Iowa. www.ag.iastate.edu/iaexp/reports/ewss_geology.pdf. Last visited 20 March 2004.
- Sobsey, M.D., L. A. Khatib, V. R. Hill, E. Alocilja, S. Pillai. 2004 Pathogens in Animal Wastes and the Impacts of Waste Management Practices on Their Survival, Transport and Fate. National Center for Manure and Animal Waste Management. Raleigh, North Carolina. www.cals.ncsu.edu:8050/waste_mgt/natlcenter/whitepapersummaries/pathogens.pdf. Last visited 29 July 2004.
- United States Department of Agriculture. 1992. Animal Waste Management Field Handbook. Washington, D.C.
- United States Environmental Protection Agency. 2000. National Water Quality Inventory. Washington, D.C.
- United States Environmental Protection Agency. 2001. Environmental Assessment of Proposed Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations. Washington, D.C.
- United States Environmental Protection Agency. 2004. Potential Environmental Impacts of Animal Feeding Operations. www.epa.gov/agriculture/ag101/impacts.html. Last visited 29 July 2004.
- Van Wyhe, N. 2001. Flushing systems pros and cons. Dairy Manure Systems: Equipment and Technology. Proceedings from Dairy Manure Systems: Equipment and Technology. Natural Resource, Agriculture, and Engineering Service NRAES-143. March 20-22, 2001. Rochester, New York.
- Waterwatch Victoria. 2004. Turbidity (suspended solids). www.vic.waterwatch.org.au/fortheteacher/manual/sect4d.htm. Last visited 28 July 2004.

Weeks, S.A. 2001. System selection for small farms. Dairy Manure Systems: Equipment and Technology. Proceedings from Dairy Manure Systems: Equipment and Technology. Natural Resource, Agriculture, and Engineering Service NRAES-143. March 20-22, 2001. Rochester, New York.

White, C. 2004. Diagram of the nitrogen cycle. Waterkeeper Alliance. Tarrytown, New York.

White, C. 2004. Diagram of the phosphorus cycle. Waterkeeper Alliance. Tarrytown, New York.